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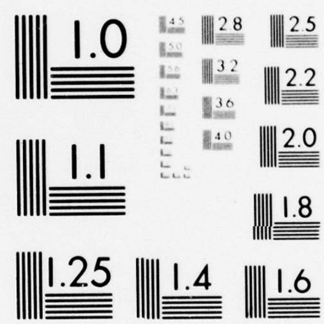

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FOREIGN TECHNOLOGY DIVISION

RADIOTELEMETRY OF MAN-MADE SATELLITE

by

Wu Ling-yao

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EDITED TRANSLATION

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Radiotelemetry of Man-made Satellite
By
Wu Ling-yao

In last issue of this journal, the first half of this article was published. The following is its second half, which continues to introduce the methods and principles of radiotelemetry of man-made satellite.

While a satellite is flying in the space, in it there are numerous engineering parameters and exploration parameters, which those who are working on the ground want to know. Sensors, explorers and distant-sensors are here and there in the satellite, and the telemetric parameters are always hundreds in number. About the engineering parameters and exploration parameters, what people want to know most is the rule of their continuous changes follwoing the change of time. This obviously requires a telemetric system to be able to transmit the huge number of parameters without interruption. Should each telemetric signal be modulated on one carrier wave, there must be hundreds of emittors equipped in a satellite. Certainly this is not economical nor practical. But if the telemetric signals sent out from any sensors are at the same time modulated on one carrier wave, these signals will be undoubtedly mixed together into a mess. This situation is just like many different kinds of grain on one vehicle to transport, when they arrive at the receiving station, there is no way to sort them out properly. Isn't there any way to transmit several telemetric signals at the same time without being messed up and they can be properly differentiated on the ground? "Nothing is hard in this world if you dare to scale the heights". Through practices, a few multi-path telemetric methods have been found. Among them, two methods are often adopted: one is frequency difference multi-path and

the other is time difference multi-path.

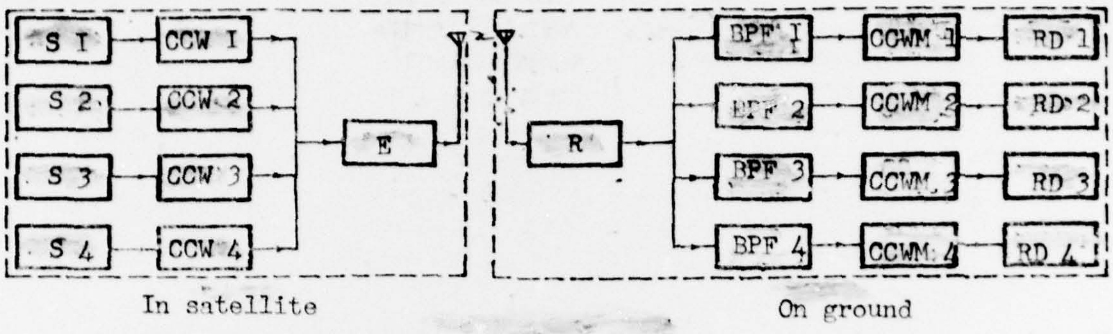


Figure 7 Diagram of frequency difference multi-path telemetering

(Note: S=sensor, CCW=co-carrier wave, E=emittor, R=receiver, BPF=band pass filter, CCWM=co-carrier wave modulation, RD=recorder.)

Frequency Difference Multi-path Telemetering

Taking transporting grain for example, there are No.1, No.2, No.3 and No.4 four different kinds of grain, which must be transported to one place. Before loading them, put 100 catty of No.1 grain in a bag; 120 catty of No.2 in a bag; 130 catty of No.3 in a bag; and 140 catty of No.4 in a bag, load all the bags on one vehicle. When they are transsported to the receving station, they can be differentiated according to the different weights of the bags. In the same manner, four telemetric signals can be transmitted at the same time. Let the four telemetric signals be modulated respectively on four oscillations of 1 kilohertz; 2 kilohertz; 3 kilohertz; and 4 kilohertz four different frequency. These four modulated oscillations are called co-carrier waves, and they are put together and modulated on an emittor. Then a carrier wave carrying these co-carrier waves is emitted out from the emittor. After being received at the ground station, the carrier wave is

first filtered through a band pass filter. The band pass filter permits only the wave of a fixed frequency to pass. As in Figure 7, band pass filter 1 only permits waves of 1 kilohertz to pass, band pass filter 2 only permit waves of 2 kilohertz to pass and so on. Thus the four co-carrier waves of 1 kilohertz, 2 kilohertz, 3 kilohertz and 4 kilohertz can be separated by four differeent band pass filters. Then the four co-carrier waves are demodulated and the telemetric signals carried down by them can be taken out. Because this kind of multi-path telemetering uses the frequency difference of the co-carrier wave to differentiate the telemetering path, it is therefore called multi-path telemetering separated by frequency difference and it is abbreviated as frequency difference multi-path telemetering.

In a frequency difference multi-path telemetric system, between frequency of two co-carrier waves, there is an interval, which must be large enough to prevent their mutual interference. The number of path and the number of co-carrier wave cannot be too many, because the more are the co-carrier waves, the smaller is the interval between frequency of two co-carrier waves so the easier is the mutual interference. At the present time, the number of paths in frequency difference multi-path telemetering is no more than 15.

In order to carry out frequency difference multi-path telemetering efficiently, in a telemetric system, there should be sufficient number of co-carrier wave oscillators and adequate technique of co-carrier wave modulation. The modulation of co-carrier wave for telemetric signals can be either amplitude modulation, frequency modulation or phase modulation. The modulation of carrier wave for co-carrier wave can also be any of the

above three modulations. Thus they can be combined into a fashion of amplitude modulation---amplitude modulation (the former is co-carrier wave, and the latter is carrier wave), amplitude modulation---frequency modulation, frequency modulation---frequency modulation, frequency modulation---phase modulation, nine "two-fold modulation". Because frequency modulation system has the merit of strong interference resistance ability and wide frequency band, this system is now adopted widely. In recent years, following the development of locking phase technique, some ground station has begun to use locking phase method to receive phase modulated wave. This method has proved able to promote the accuracy of telemetric signals, and the carrier wave phase modualtion has therefore become popular.

Time Difference Multi-path Telemetering

Of the multi-path telemetering separated by time difference, abbreviated as time difference multi-path telemetering, the principle is that the emittors in a satellite rotatively emits each telemetric signal at different time. Again taking transporting grain for example, when the vehicles come over one after another, the first vehicle is assigned to carry No.1 grain, the second vehicle, No. 2 and so on. When the fifth vehicle comes, it is asked to carry No.1 grain, the sixth vehicle, No.2, so on and so forth. The receiving station then can differentiate the kinds of grain according to the order of the arrival of vehicles. In the transmission of telemetric parameters, the time order is like the order of the vehicles. The emittor uses the first time interval to emit telemetric signals of sensor No.1, uses the second time interval to emit signals of sensor No.2 and so on. Then it uses the fifth time interval to emit signals of sensor No.1, so on and so forth. The work of emitting telemetric signals in rotation can be

performed by a path alternator. The path alternator connects the four sensors to the emittor rotatively, and thus the telemetric signals modulated on the carrier wave at different times are four separate telemetric signals (Figure 8). Correspondingly, at the ground station, there is also a path alterantor, which can differentiate the four telemetric signals based on the order of time. The path alternator at the ground station must work strictly at the same pace with the path alternator in the satellite (Figure 9). Otherwise, it will make wrong identifications by "putting Chang's hat on Li's head" as it can mistake the telemetric signals of sensor No.1 for those of sensor No.2.

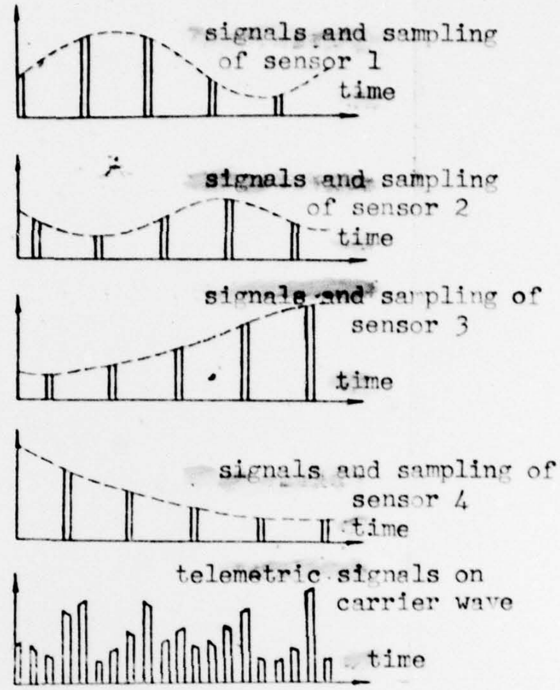
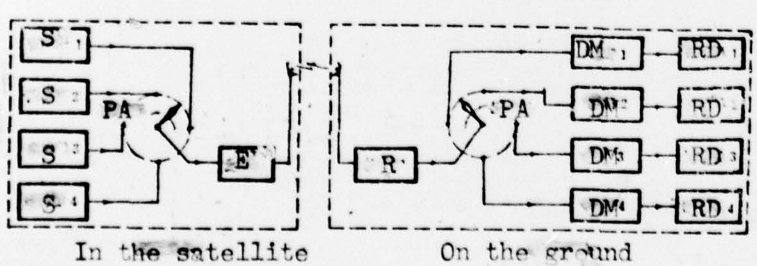


Figure 8 Sampling and carrier wave of time difference multi-path telemetering



(Note: S=sensor, PA=path alternator, E=emittor, R=receiver, DM=demodulation, RD=recorder.)

Figure 9 Diagram of time difference telemetering

From Figure 8, it can be seen that time difference multi-path telemetering is in fact to separate the continuously changing telemtric signals into isolated ones to send out. The path alternator takes one value of the telemetric signals sent out from a asensor when it makes one contact with the sensor. Such a process is called sampling. What is received on the ground is also a isolated signal. Can these isolated signals represent the original continuously changing signals? Theorectically it can prove that if the times of sampling per second from the telemetric signals are as many as two times more than the highest frequency of the telemetric signals, the isolated signals received on the ground can perfectly represent the original continuously changing signals. In fact, it takes a very short moment for an electronic path alternator in a satellite to connect one sensor from another, and it takes also a very short moment for one sensor to connect another. So even though the sensors in a satellite are many, the time interval between two samplings of each telemetric signal is still very short. And most of the changes of the engineering parameter and the exploration parameter are slow, and their highest frequency is slow, too. It is therefore completely possible to have the times of sampling per second two times more than the highest frequency. Certainly, for the telemetric parameters,which change very fast, it is necessary to use frequency difference multi-path telemetering to transmit.

In practical systems, both the frequency difference multi-path telemetering and the time difference multi-path telemetering are used jointly, so that one's shortcomings can be made up by other's strong points (Figure 10). Thus the fast changing parameter of frequency difference multi-path telemetering and the slow changing parameter of time difference multi-path

telemetering can be complementary to each other.

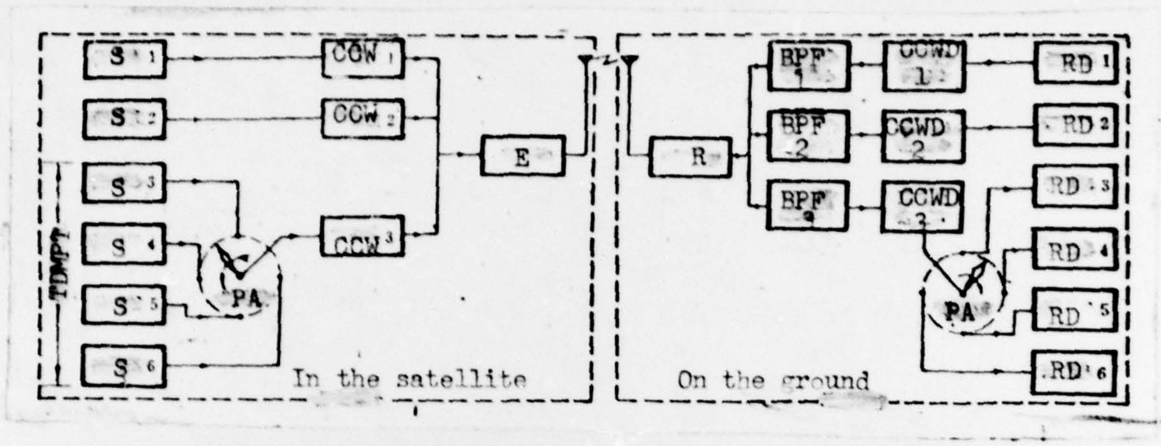


Figure 10 Diagram of a combination of frequency difference multi-path telemetering and time difference multi-path telemetering

(Note: TDMPT=time difference multi-path telemetering, S=sensor, PA=path alternator, CCW=co-carrier wave, E=emittor, R=receiver, BPF=band pass filter, CCWD=co-carrier wave demodulation, RD-recorder.)

Pulse Code Modulation

Since the telemetric system is a system to make survey and to send data of a long distance, the most important indicator of the quality of the ability of the system is wether the telemetric parameters can maintain their originality without distortion after being transmitted through a long distance and wether the parameters demodulated on the ground has little error. Errors in telemetering are mostly caused by interference of the straying electric waves during the transmission.

At present, in telemetric system of man-made satellite, the pulse coding modulation method is widely adapted, and the name of the method is abbreviated as pulse code modulation. It is an advanced modulation system, which can help increase interference resistance strength and promote accuracy of the telemetering.

As stated above, the delivery work performed by a sensor is a voltage signal, which is in a proportion to the size of the surveyed parameter. Because it uses the change of voltage to analogize the change of the surveyed parameter, it is therefore a kind of analog signal. The modulation mentioned above refers to that which uses this kind of analog signal to modulate co-carrier wave or carrier wave and to make their amplitude (frequency or phase) change continuously following the high-low voltage change of the analog signal. Modulation of this kind is called analog modulation. The pulse code modulation is a digital modulation, which is essentially different from analog modulation. Its characteristic is that the signals sent out from a sensor must first make a "pulse coding". To"transform"analog signals into digital pulse signal is to modulate co-carrier wave or carrier wave based on the fact of ~~wother~~ whether there is a pulse or not. The process of this "transformation" includes three steps: sampling, quantization and coding (see Figure 11).

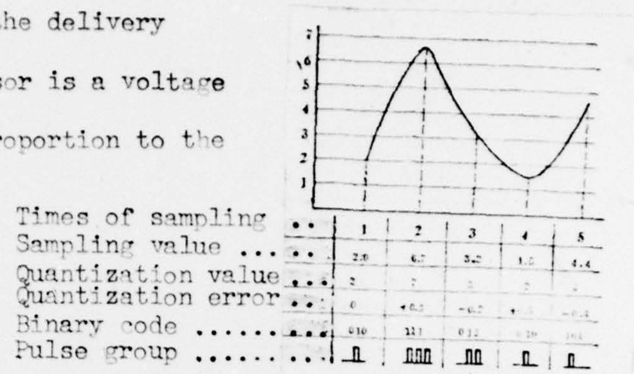


Figure 11 The process of pulse code modulation reformation

The first step is to sample from the analog singals of the telemetric parameters sent out by a sensor, and to change the continuous signals into a series of separate value of different time interval. This process is same as the sampling in time difference multi-path telemetering. The number of times of sampling the analog signals of each path should be as many as two times more than the possible highest frequency.

The second step is quantization. It is to change the number value acquired from sampling into standard value, which is also called quantization value. The method of quantization is to divide the maximun value of analog signals into 2^n stratums, and any one integral number value from 2^n stratums can be taken as standard value. For example, if $n = 3$, $2^n = 8$, then the possible maximum value can be divided into 0, 1, 2, 3, 4, 5, 6, 7 eight stratums, and any sampling value can be changed into any one from 0 to 7 of the eight integral number values. In Figure 11, for example, the third sampling value is 3.2, which can be made a quantization value 3, and the missing 0.2 is called a quantization error.

The third step is coding. After changing sampling value into quantization value of integral number, the quantity value of integral number still remains analogous. The important step is to change it into binary digits. The number of digits in the binary number is the n value selected from the quantization stratum. If $n = 3$, the humber will be of three-digit, from 0 to 7 eight numbers as indicated in the following scale.

Quantization value	0	1	2	3	4	5	6	7
Binary digit code	000	001	010	011	100	101	110	111

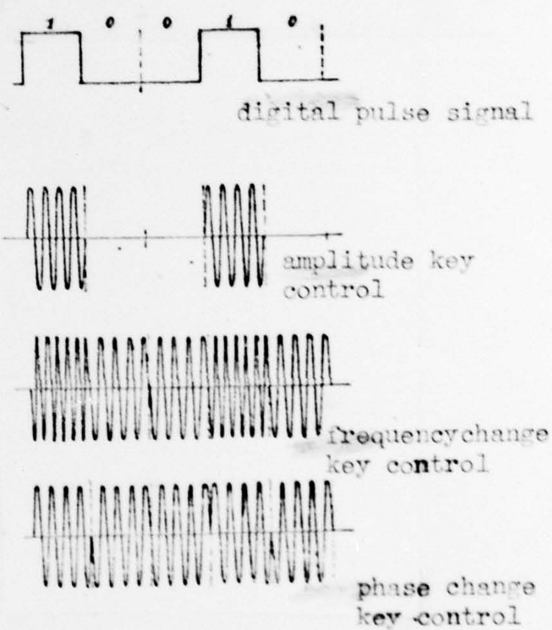


Figure 12 Three modulation methods of pulse modulation

After the sampling value being changed into binary digit code, the numbers can be indicated by both positive pulse and negative pulse. A

positive pulse inducates "1" and negative pulse "0". So three continuous pulses indicate 111 (or 7). Negative pulse at both ends but one positive puplse in the middle, they are 010 (or 2). Then pulse group modulates on co-carrier wave or carrier wave. Using positive and negative pulse to modulate is in fact to practise a switch type control over co-carrier wave or carrier wave, so this kind of modulation is called key control. For instance, in co-carrier wave modulation, when there is a positive pulse, the co-carrier wave appears and its amplitude is normal; when there is no pulse (negative pulse), the co-carrier wave does not appear and its amplitude is zero. This is called amplitude key control. In frequency modulation, when there is a positive pulse, the frequency of co-carrier wave shows an inclination; when there is no pulse (negative pulse), the co-carrier wave maintains a center frequency. This is called frequency change key control. By the same principle, phase modulated by positive and negative pulse is called phase change key control. When there is a positive pulse, the co-carrier wave phase inclines by 180°; when there is no pulse (negative pulse), the phase is normal (Figure 12).

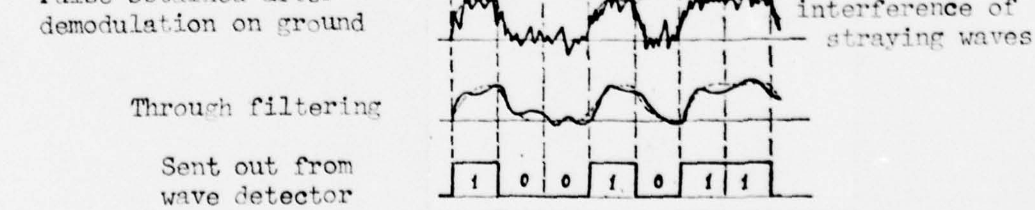


Figure 13

The great advantage of using pulse code modulation method is that it can free the telemetric signals from interference by the straying electric waves when they are being transmitted. When a carrier wave is emitted from a satellite to the ground station, its amplitude often changes because the interference of the strying electric waves, and as a result, some additional amplitude modulation comes out. When amplitude is modulated by analog modulation, this additional amplitude modulation will become an error. In pulse code modulation, as the carrier wave from an emittor has amplitude key control, when demodulation takes place on the ground, there is only the necessity to see if there is carrier wave and nothing to do with the size of the carrier wave amplitude, so the additional amplitude modulation caused by interference causes no problem to the whole process. From Figure 13, it can be seen that because the carrier wave is interfered by the straying electric waves in the course of transmission, its amlitude has some extraordinary changes. When it is received on the ground, the pulse obtained through demodulation is almost entirely different from its original shape. But in wave detecting, it only needs to see if there is carrier wave. All that of which the amplitude is not lower than one half of the normal value can be restored as a whole pulse, and that of which the amplitude is lower than one half of the normal value is no-pulse or negative pulse. Only in the case of extraordinarily strong interference, the amplitude of carrier wave can become lower than one half of the normal value, and only at the time interval when there is no pulse, there appears an extra amplitude, which is more than one half of the normal value, then comes the error of confusing 0 and 1. However, the chance of having such an extraordinarily strong

interference is rare. Similarly, in frequency change key control and phase change key control, in the demodulation on the ground, there is only need to see if there is frequency change and phase change, and there is nothing to do with the magnitude of inclination. Even though the inclination value can change because of interference, generally, however, it will not cause any error. To the frequency and phase modulated by analog modulation, the magnitude of frequency change and phase change represents the size of telemetric signals. So the additional frequency change and additional phase change caused by interference can lead to make error in telemetric signals. It is therefore evident that through such a "reformation" by pulse coding, the interference resistance ability of the telemetric signals is greatly strengthened. Compared with analog modulation, pulse code modulation can minimize error and promote accuracy of telemetering. But in quantization, pulse code modulation keeps its decimal fraxtion part in dark and is treated as intefral number, thus it brings some "quantization error". The way of reducing quantization error is to increase the number of stratums and to narrow the interval between stratums.

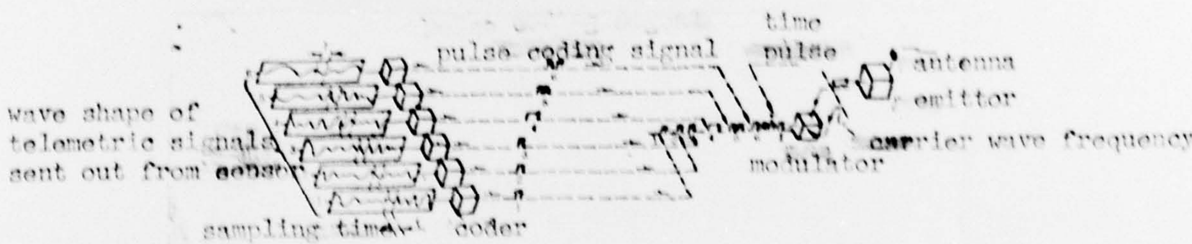


Figure 14 Diagram of pulse code modulated time difference multi-path telemetric system in a satellite

Most of the pulse code modulation system are of two-fold modulation. The digit pulse telemetric signals are modulated on co-carrier wave and the the co-carrier wave is modulated on carrier wave.

It is an analog-to-digital converter, namely a coder, that is used to change analog signals into digit signals. In pulse code modulation telemetric system, between the sensor and the emittor, there is a coder (Figure 14). Correspondingly, at the ground receiving station, there is a set of equipment, which can be used to convert digit signal into analog signals. It is called digital-to-analog converter or a decoder. So the binary digital code after demodulation can be changed into analog signal voltage, and after amplification, they can be recorded and disclosed.

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